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Smart cities and digital workplace culture in the global European context: Amsterdam, London and Paris

Michelangelo Vallicelli

Roma Tre University - Architecture Department, Largo G. Marzi 10, Roma, Italy

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ABSTRACT

Until recently, knowledge-intensive work activities have predominantly taken place in office buildings as a specialized form of economic infrastructure. New digital technologies together with an economic and organizational transition from closed firms to open platforms has changed the pattern of work within the modern metropolis. The office building is no longer the sole workplace typology and work activity has intensified in other urban locations. The questions then are: "How might smart cities reinterpret workplace culture at the urban scale outside the framework of office buildings typology?" and "Which tools and methodologies can be used to make digital workplace culture visible at the urban scale?" In order to answer these questions, workplaces are observed not as private architectural spaces but as compositions of "subjective urban experiences". A Twitter data analysis provides evidence of workplace spatial culture within the innovative global cities of Amsterdam, London and Paris, interpreted as behavior settings. This analysis shows that office pattern locations are generally distributed independently to knowledge intensive business services and workplace demand, as expressed through social media analyses. In addition to office buildings, transit hubs, urban amenities and new digital services play a key role in reframing workplace location. Moving beyond generic visions for digital work in outer spaces, big data therefore provides specific insights and incentives for considering workplace design at the urban scale.

1. Introduction: office typology, urban space and collaborative technologies

Understanding the implication of digital technologies within the workplace[1] – taken here as the combination of behavioural and physical factors – requires a perspective that goes beyond an architectural approach to consider the role of urban design. Despite its prevalent, modernist definition, “office” historically referred an urban space rather than a private room or building. During the renaissance, Florence's *Uffizi* (“Offices,” today a museum), designed by G. Vasari, became Europe's first office-based service centre. The building, a void corridor carved into the pre-existing medieval fabric of its site, is defined by its horizontality and a design that is flexible in the use and configuration. It was a major urban development and centralized the administration of emerging capitalist companies in a public space, situating them in the city's politics.

Thanks to mass productivity (see Taylor, 1911; Rullani, 2004), office activities eventually moved from factory counting houses to skyscrapers (Saval, 2014), increasing their density and complexity within cities. Especially in North America, business districts have been fundamental in localizing large volumes of offices in central locations. Following L. Sullivan's definition of modernism in architecture, according to which “form ever follows function” (Sullivan, 1896), the office typology figures as the main field of modernist experimentation, and anchors metropolitan developments. Starting from the interior design and layout of single office cells, Sullivan's urban ideal is based on a vertical multiplication of this primary organization, generating entire cities of skyscrapers, which he compared to “hives”. In this vision, the original ideal of the office as a “public space” is replaced by an urban idea based on private, enclosed environments.

The office-tower form that dominates the skyline of 20th century downtowns in US cities like New York and Chicago has been more recently integrated into global city centres such as Hong Kong and London. However, in many European cases, the existence of already saturated inner historical areas means that this typology has mostly characterized a second-stage peripheral expansion, as shown by Firley and Gimbal (2011). While mostly concerned with housing issues, European modernism only turned its attention to management centres at a late stage (1930–1950), critically reinterpreting North American skyscraper developments. Unrealized proposals, such as Le Corbusier's *Plan*

E-mail addresses: michelangelo_v@yahoo.it, micheleangelo.vallicelli@uniroma3.it.

[1] In this case, the process of “knowledge-work” (Drucker, 1957, p. 122) digitalization will be accounted for in opposition to manufacturing, therefore excluding implications such as robotics in factories.

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Voisin, *Ville Radieuse*, or *La Cité des Affaires* project for the *Plan Obus* have shaped the language of later-realized European global service centres.

After World War II, digital technologies migrated from their main military applications to office workplaces, which became their biggest commercial pool. Personal computers and later the Internet caused an intensive shift in productivity, forming a new "informational society" (Castells, 1996). From the beginning, the process of workplace digitalization has inspired many architectural and urban visions that prefigure the "death of the office" (see Vegesack, 1998). In 1980, the futurologist A. Toffler theorized the image of the "electronic cottage" to describe rural and domestic work locations could be rediscovered through remote-work, giving birth to a new "home-centred and rural society" (Toffler, 1980) outside of congested business districts. More concretely, new telecommunications, together with infrastructural developments, have influenced numerous dislocative investments and strategies, such as "edge cities" (Garreau, 1991) or "edgeless cities" (Lang, Sanchez, & Oner, 2009), or those defined by R. Fishman (1987) as "technoburbs", between 1980 and 2000.

As described by Castells, "informational society" fundamentally involves new types of labour and their relationship with inner cities. In contrast with earlier conceptions, which foresaw office developments' ubiquity and their relocation to peripheral and rural areas, the new global economy or "global cities" phenomenon (Sassen, 2005) concentrated knowledge intensive business services in city centres in order to coordinate information flows of increasing complexity.

As largely discussed in the literature, what emerges as the current and future challenge for urban design is not rural relocation but urban densification. Moreover, what becomes evident is that, in contrast with early visions, central offices are still intensively built and are three times more expensive other urban real estate sectors (Hutchings, 2015, p. 21). Office typologies – especially high-rise office towers – are the most expensive large scale architectural projects in terms of energy consumption and construction costs (Snow, 2014, p. 20), raising additional questions of urban design sustainability. Finally, even if it is still not clear how vacancy rates may be directly dependent on workplace digitalization, a strong decrease of surface per employee ratio has been observed since 2008 (Miller, 2014).

Even if workplace digitalization isn't a novel issue, the recent combination of several radical transformations affecting not only work-related activities but the overall urban productive chain put this topic into a new perspective:

1) **Mobile and collaborative media pervasiveness:** since 2008, increasing freelance and entrepreneurial activities has allowed for the unprecedented spread of personalized and mobile collaborative media. This has enabled workers to combine interactivity with work-related communication tools at a global scale that exceeds the single firm and "office" environment. An individual can now easily collaborate with the rest of the world in real time.
2) **Firms are turning into platforms:** where previously service organizations – identifiable in their office buildings – were able to shape society and urban conditions, today the behavioural complexity of urban ecosystems is itself the main resource for productivity and innovation. This justifies the recent and increasing relocation of knowledge intensive companies to downtowns as they look for a return to centrality (Katz & Wagner, 2014).
3) **Smart cities:** digital technologies don't only impact individuals: they are progressively integrated within administrative organizations for urban policies and design. That means civics demands are increasingly supplied by digital solutions and tools, making the urban public sphere "digitally augmented" (Picon, 2015, p. 95).

In this context, a paradox emerges: if work distribution is increasingly controlled by digital technologies, this is not producing place annihilation but rather local intensification. On one side, office typologies and their large urban agglomerations still appear to be unsustainable (Duffy, 2008); on the other, the city is definitively not a place to escape from for knowledge industries and knowledge-work practices, even in their mobile condition. For this reason, understanding the role of digital media requires understanding workplace as "behaviour settings" instead of only as a location in space (Barker, 1990): in the condition of digital work, as B. Jordan points out (2005, p. 3), workplaces can be understood as "workscapes": subjective experiences or "histories" related to diverse environments which exceed the office space. The methodological contribution of this paper deals with how and why to make digital "workplace culture" visible, [2] building knowledge for a data-driven urban design strategy within the European context. I do this by comparing georeferenced Twitter data analysis with GIS spatial data for three European global cities: Amsterdam, London, and Paris.

The use of social media location-based services, more than giving objective evidence of work-related practices in space, provides insights into how "collective projections" or desires map over space. This is coherent with the purpose of understanding a workplace not only as a mere space but as a behaviour setting at the urban scale, showing work as a cultural practice. If space has lost its capacity to control the production chain, which is currently absorbed by digital media, then the demand for a centralization of work activities depends on relational and cultural needs. The informal nature of mobile work reveals a strong demand for the city not sufficiently met in terms of a structural rethinking of urban spaces.

2. Approaches to urban form, digitalization and innovation districts

Research literature has approached workplace digitalization from several perspectives: the largest contributions in this field are from ethnography, sociology, and management theories that consider workplace as a set of human relations and media. [3] As this paper is concerned with design issues, it will refer to those recent contributions in which workplace is intended as a complex agglomeration of human organizations, behaviours, media, and material spaces. While recent architectural discourse about collaborative or home-office spaces has addressed these factors, to my knowledge, urban design implications have not been raised. This contribution becomes crucial as "communication at work constructs our working spaces and our working environment" (Roth-Ebner, 2015, p. 1), and communication space exceeds the limits of enclosed, private architectures. Meanwhile, aspects such as innovation, information communication technologies (ICT), and knowledge districts have been widely related to the notion of urban form.

2.1. Information technologies and urban form

One of the first major studies which relates communication theory to urban organization is R. Meier's *A Communication Theory of Urban Growth* (1962), which describes how knowledge, communications, and interactions promote agglomeration processes. According to M. Webber's (1964) previsions, this implies not only physical changes such as movement but also effects on "patterns of mind". Webber observed the need to shift the urban design discussion from the conception of "place" to "connectivity", seeing the city as a web of interactions and witnessing a progressive intersection between planning and social sciences. His work has been crucial for more recent literature focusing on

[2] This term "workplace culture" counterposes the idea of a "workplace" as a mere space with a "workplace" as a set of meanings.

[3] This concept of workplace has been widely studied by Jordan (2008) and more specifically for the European case by Gareis, Lilischkis, and Mentrup (2006). From a theoretical perspective "mediatized work" (Roth-Ebner, 2015, pp. 1–2) has also been defined by Wimmer and Hartmann (2015).

networks and ICT including Castells (1996) and Graham and Marvin (2002).

In terms of major global changes, Castells underlines how increasing productivity in the computer industry might affect the overall economy if labour adapts to these new processes. Informational networks have progressively shaped "specialty labour" including "top business managers, financial analysts, advanced services consultants, scientists and engineers, computer programmers, biotechnologists, and the like" (Castells, 1996, p. 130) as a global factor for productivity and consumption. Even if ICT are not precisely a causal factor for work's structural changes, [4] their major implication is not the reduction of material vs. immaterial activities but *routines*: machines, and specifically for offices, computers, are able to reduce the number of repetitive tasks workers perform. The main value of work therefore becomes "innovation", and cities become engines for this productive purpose to the extent that they are capable of centralizing global workforces.

2.2. Innovation districts

B. Katz and Wagner (2014) defines "innovation districts" as an emerging spatial trend in location preferences for knowledge industries oriented towards physical compactness, transit accessibility, heterogeneity, and centrality. This is in contrast to the prior dominance of suburban corridors such as Silicon Valley (Katz & Wagner, 2014, p. 1). In rediscovering J. Jacobs's (1960) "mixed land use" concept, we can begin to see existing urban resources, car-free mobility, diversity of socio-economic environment, and proximity, and not the modernist features of large-scale office buildings in functionally uniform areas, as drivers for innovation and revitalization. The spatial features of knowledge industries (e.g. "proximity" and "heterogeneity") have been recently measured in depth by G. M. Spencer (2015) and S. Hawken and J. H. Han (2017). These studies consider several data sources that show different results from previous understandings that saw generalized proximity and heterogeneity as uniformly good for knowledge district design and land-use categories. As S. Hawken and J. H. Han (2017) argue, urban design needs to understand spatial factors like heterogeneity beyond the generic concept of mix promoted by practice and academia as a productive strategy for urban areas and urban innovation. If this literature has recently foregrounded the relevance of urban space for innovation, this paper aims to further relate these concepts to the "culture" of digital work, which is not often integrated at the core of an urban design discourse.

3. Digital placemaking, smart cities and urban workplace design

In smart cities, media becomes a constitutive urban component, allowing for discussion of "media cities" (McQuire, 2008). In looking at "workscapes" (Jordan, 2005), the way in which collaborative media augment urban space becomes crucial for urban design. Recent investigations by A. Townsend (2011) have considered mobile-work practices from their ethnography to workplace design, proposing provocative visions of how knowledge-workers might "escape from the office" thanks to digital technologies. While this contribution clearly addresses issues that relate urban design to the mobile condition of knowledge-work, it does not compare context morphology to a proper urban geography. While qualitative and empirical implications are understood locally – analysed for each place – a holistic analysis of urban morphology has not been conducted at the scale of the city.

The recent emergence of a vast and varied set of networked and mobile technologies have made physical space a primary resource: in many cases, these applications allow for the georeferencing of metadata, thus becoming "spatial media" (Kitchin, Lauriault, & Wilson, 2017). Spatial media such as Twitter simultaneously consume and produce a large amount of data. [5] One way to make sense of them is through "spatial data analysis": the process through which decision making can be generated from the georeferenced data (Miller, 2017). The most relevant potential that this paper observes is the capability of these tools to link "cultural content" (Manovich, 2009) to space, which is in line with the purpose of understanding the digital workplace in cultural terms for urban design decisions.

Thomas A. Horan in his book *Digital Places: Building our City of Bits* (2000) expands W. Mitchell's concept of "recombinant architecture" and the practice of "recombinant design" to the scale of "digital placemaking". [6] ICTs in this approach affect urban space, where "… settings, communities, and cities are constantly being reinvented based on a complex interweaving of economics, culture, technology, and circumstance." Horan goes on to point out that "integrating technology into our day-to-day places should not be left strictly in the hands of network designers. […] A firm understanding of the content, context, and values embedded in existing physical and social communities must guide each design decision" (Horan, 2000, p. 13).

In this sense, "digital placemaking" shifts the design target from mere buildings to places, making digital work an urban practice that extends beyond the office or co-working environment. Issues surrounding architectural configurations can then be integrated into an overall urban vision for digital work as an adaptive cultural process. ICTs and mobile technology don't merely constitute a neutral environment for urban experiences: they play an active role in how urban practices take place (Zwijnenberg & Zijlmans, 2014, p. 67). Thus, this paper aims to analyse digital work as a process of reinterpretation – or a "translation" – of city through practices.

To avoid the idea that knowledge-work digitalization is leading to the vague and undifferentiated concept of "virtuality", it needs to be represented in urban space through maps able to describe it in terms of a demand and supply ratio.[7] As F. Duffy argues, "We need to reverse the malign aspects of the office supply chain that we have inherited from Taylorism. […] In fact, so different should this new supply chain be that it might be better described […] as the exact opposite, a 'demand chain', which would start with the users rather than investment" (Duffy, 2008).

This paper argues that a social media analysis can provide knowledge related to demand. A broad range of social research has recently focused on Twitter to understand innovation communities through "webometrics" (Choi, Park, & Park, 2011; Procter, Vis, & Voss, 2013).[8] Here, however, Twitter data are not intended as a social representation, since the identity of users is not considered. They are rather intended to give insights into "cultural practices" related to urban space as a means of describing workplace demand.

4. Comparing three cities in the European global context: Amsterdam, London and Paris

Before dealing with "proposals" or "decisions" for urban design, it is necessary to make the digital work phenomenon visible in its current condition. Amsterdam, London, and Paris are three European cities characterized by a dense historical context that intensifies meanings for places and offers a high potential for a regenerative approach. At the

[4] As Castells argues, technologies affect labour features only in combination with political and social factors (Castells, 1996, p. 130).

[5] Even if it is not its main functionality, Twitter allows location-based service functions that can be used to georeference textual or media content.

[6] W. Mitchell in his book *The City of Bits* argues that "telecommunication systems replace circulation systems and the solvent of digital information decomposes traditional building types". The process of creating digital places can be thought of as "recombinant design" (Mitchell, 1996).

[7] "Demand" is here intended as end-users' desires and projections over urban space; "supply" as what is currently designed and realized in terms of built environment.

[8] Thelwall (2009, p. 6) defines webometrics as "the study of web-based content with primarily quantitative methods for social science research goals".

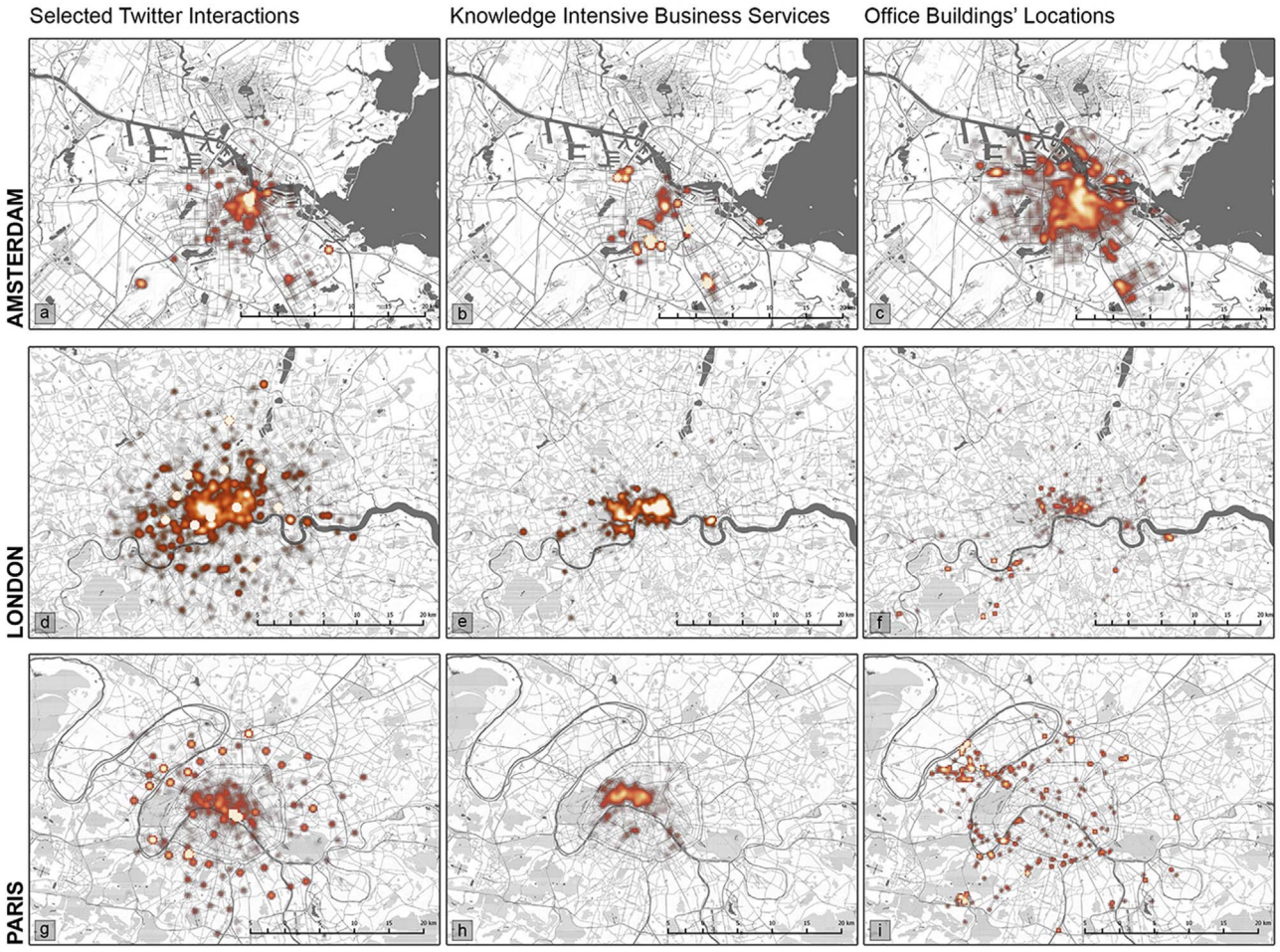

Fig. 1. This matrix shows the most significant clustering values for each dataset in the three cities.

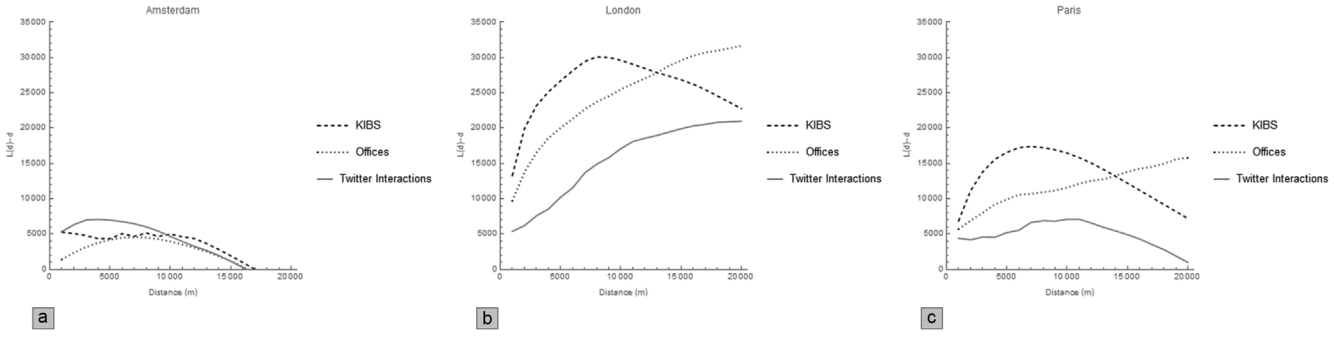

Fig. 2. L(*d*)-d values considering a maximum scale of 20 km and increasing distance d = 1 km.

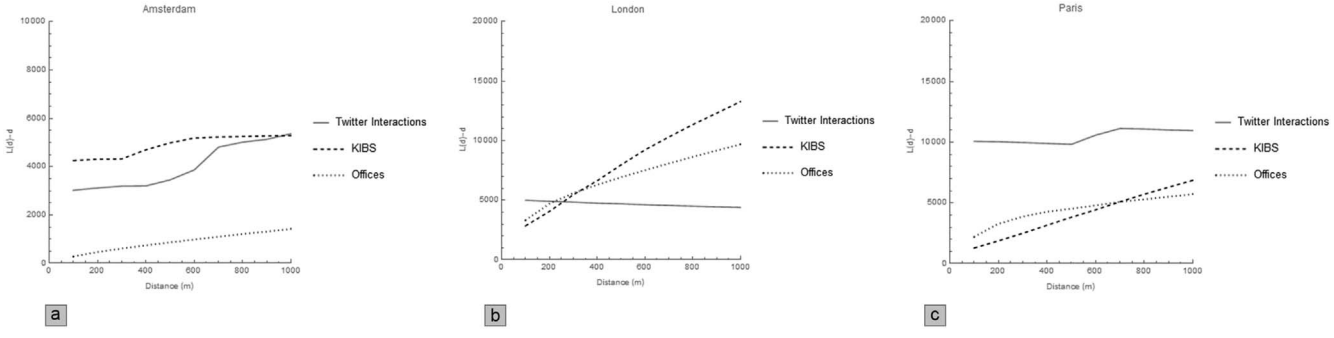

Fig. 3. L(*d*)-d values considering a maximum scale of 1 km and increasing distance d = 200 m.

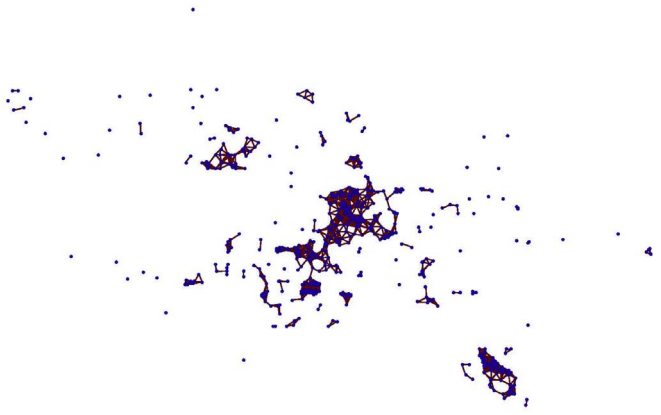

Fig. 4. The graph model of Amsterdam's knowledge intensive business services distribution derived from the proximity agglomeration given by Euclidean distance d = 500 m. The definition of edges given by proximity values allows the graph partitions to be treated as clusters.

same time, they are ranked by the Innovation Cities Program – at first, seventh, and ninth place, respectively – in the 2015 Global Innovation Index. This means that they're characterized by a high presence of advanced services, networked economies, and enterprises. According to many European reports, these industries make these cities hubs in global economies compared to other established European capitals of similar scale and population.

4.1. Historical background

4.1.1. Amsterdam

Despite its small size, Amsterdam has a central position in the global economy. Foreign companies operating global or regional office locations attract foreign workers who temporarily (or not) settle in the surrounding area. Since 1990 the municipality has undertaken large-scale regeneration strategies in close cooperation with market players and social housing associations. Responding to strong market pressure, the municipality has allowed large-scale operations to take place in the west, south, and south-east perimeter demarcated by the newly completed A10 infrastructure ring and new light rail connections. These projects were developed with the aim of responding to accessibility while preserving the city centre. The reference model, known internationally as Transit Oriented Development, sought to join urban development for offices with the new regional rail network (Pojani & Stead, 2014). Projects such as the Bijlmer Arena or Zuidas have created a multifunctional office system that also includes luxury homes and large-scale commercial services (Evers, 2008). The recent financial crisis has essentially cancelled demand for new office buildings, revealing how much the previous management plan had contributed to a huge over-offer.

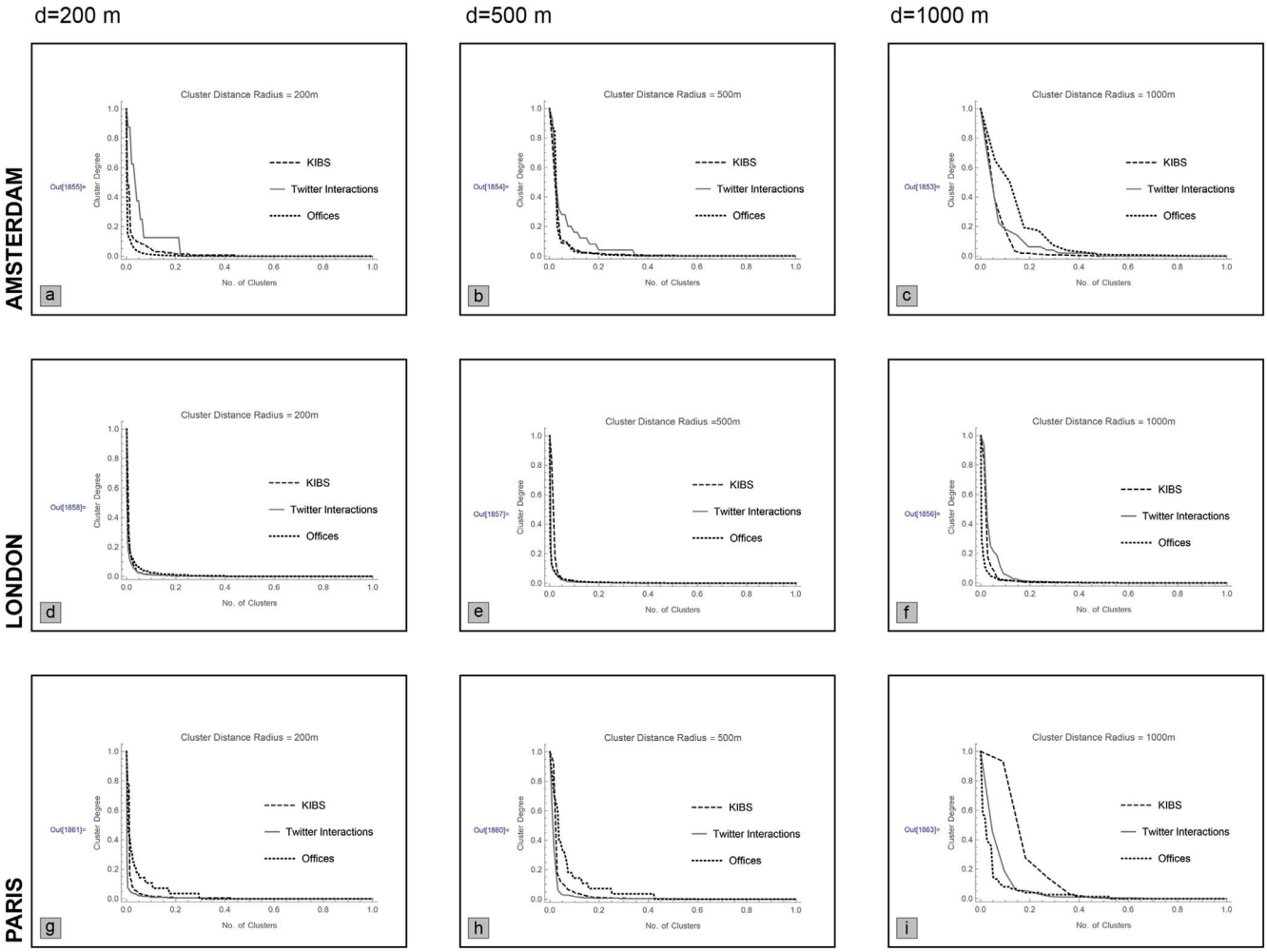

Fig. 5. The normalized (0–1) cluster analysis results based on the modularity method. A higher number of highly ranked clusters shows a "distributed" or polycentric pattern, while a smaller number of highly ranked clusters defines a more "hierarchical" or monocentric pattern of proximity.

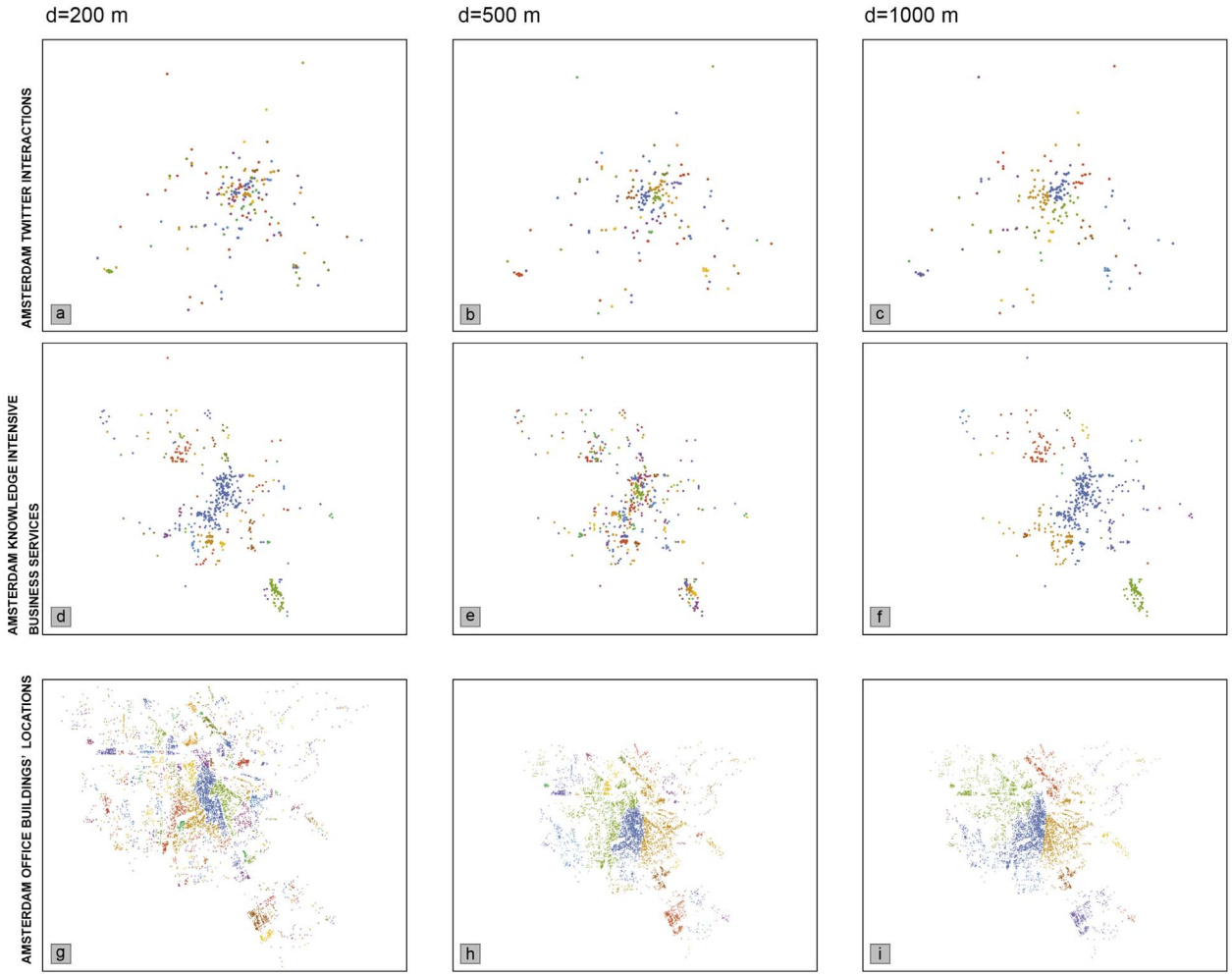

Fig. 6. The clusters mapped at their different proximity (d) values only for the case of Amsterdam.

4.1.2. London

The city of London and in particular the area known as Central London is the central hub for office activities not only in the UK economy but throughout the EU. It has the highest percentage – over 40% – of office space on a national scale, yet it is of real estate value that provides most impressive measure of concentration: a concentration of 80% more capital than the rest of the UK. According to Barras (1984), three aspects of London's economic structure explain its high concentration of offices: the high concentration of office jobs and major business functions, the tendency in the Central London economy to attract national and international services with a high proportion of office jobs, and the fact that major international companies have established their offices in London. In particular, financial institutions have been attracted to the City of London's role as the main European financial centre. The large peripheral development area of the Docklands, begun in 1980, has enabled the realization of 100,000 m^2 of offices, compared to the 30,000 m^2 built during the post-Second World War reconstruction stage of 1950–1980, when building took place mostly in the city centre. Not only are these measures higher, they have also produced an increase in overall profits over time, as they added to previous interventions in central areas. Today, however, it is possible to observe in the process a renewed centralization of knowledge-work and a revaluation of central areas as a destination for new tertiary activities. The phenomenon is the consequence of a policy of restricting extra-urban development for the city of London through measures such as additional taxation. The laissez-faire approach of the 1980s has been replaced by a regeneration program that prioritizes revitalization and strongly discourages developments outside the city.

4.1.3. Paris

Post-war expansion policies lead to the development of the city of Paris on a principle of suburbanization. The emergence of the new service economy and the infrastructure development of the RER commutator network led to the concentration of main service-use areas in La Défense. The intervention continues to play a leading role for the city today and, since 2007, has been subject to a plan for renewal that aims to adapt the area to current real estate market criteria. To speed up the process, exemptions and incentives are used to encourage both regeneration and new construction. In the first case, for example, a redesign of the development's first tower will extend its surface by increasing its height; In the second, there are plans for three new projects started in 2007: the Signal Tower, the Phare, and the Hermitage Plaza. In addition, the renewal plan has put in place a program to emphasize greater use of renewable energy and sustainability, which are currently very problematic for the area (Picon-Lefebvre, 2012). Although La Défense has always played a central role in the development of Paris's main tertiary economies, more recently, city development plans have combined a system of state, municipal authority, and private interests in their transformation of the northeast sector.

4.2. The datasets used

The purpose of this comparative study is to measure and describe the demand and supply ratio configuration in terms of workplaces. This is achieved by comparing four datasets:

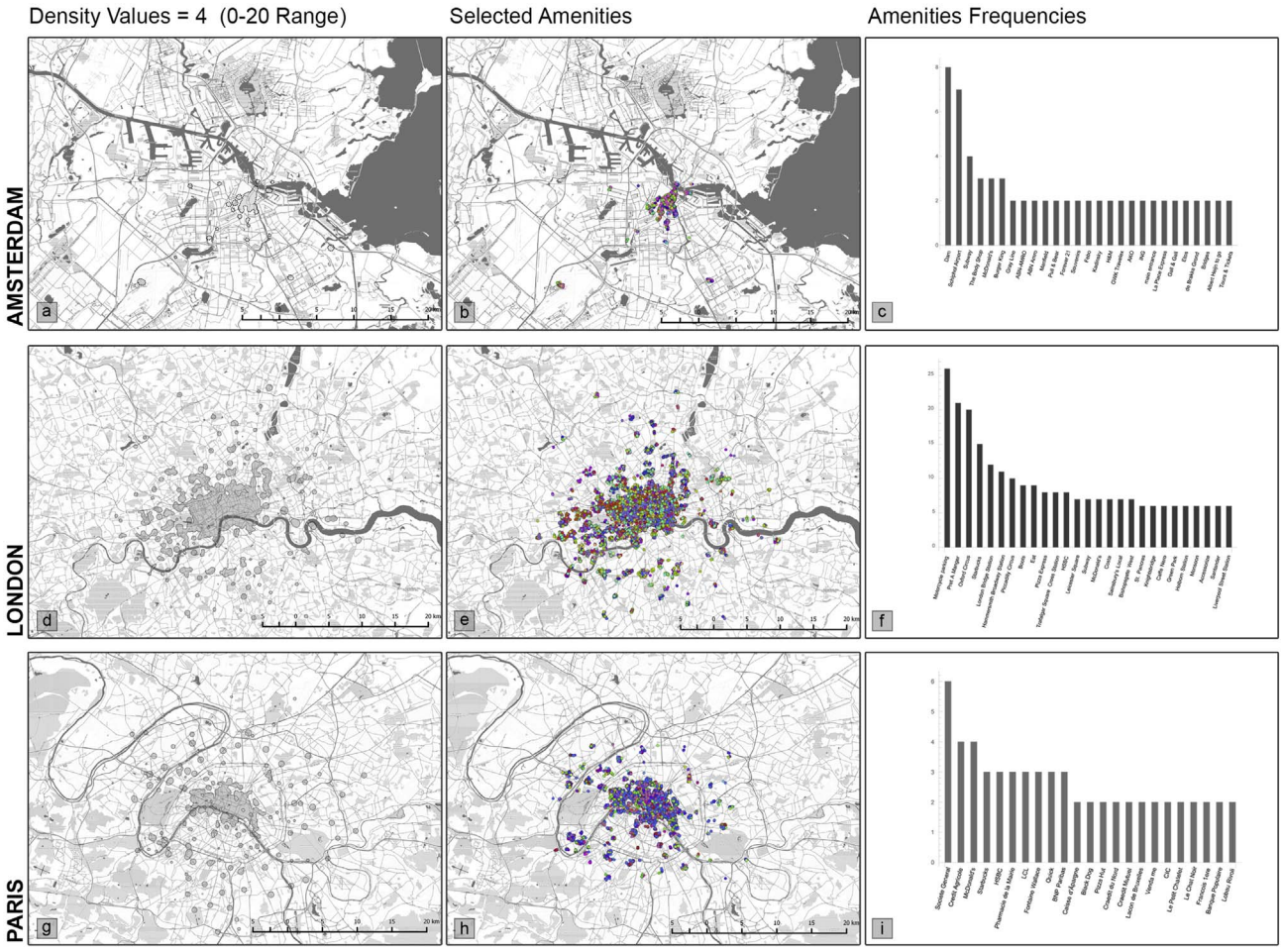

Fig. 7. The frequency (count of nearest points) of closest amenities to defined Twitter interaction densities. Frequencies = 1 have been excluded.

1) The georeferenced record of knowledge intensive business services (KIBS) interpreted as the NACE codes 61,62,63,64,71,72,90 provided by BvD in the AMADEUS project.[9] This aims to locate the current presence of knowledge-based business activity.
2) The centroids records of office building footprint polygons.[10] This gives insight on the bidimensional spatial distribution and organization of office buildings.
3) The services and activities on the ground floor of the buildings. This allows for the identification of the type of existing services closer to digital work distributions in the city.
4) A set of georeferenced Twitter interactions (TI) extracted within a period of three months and filtered through keywords identifying work-related activities. This aims to give evidence of collective projections and experiences over urban space, defining how workplace is perceived in cultural terms. Even if Twitter cannot fully describe professional activities because sharing work-related content is rare for privacy reasons, it is possible to identify those interactions promoting venues suitable for work meetings or individual and organized business activities. Moreover, even if Twitter is not a professional social network like LinkedIn, its API provides greater access to public data. A rigorous methodology for workplace identification matching Twitter and LinkedIn profiles has been conducted by Efstathiades, Antoniades, Pallis, and Dikaiakos (2015); This research uses a probabilistic "content based approach", which is less precise in terms of real workplace identification but provides a semantic map based on micro-blogs' textual content, which is more coherent when the purpose is to understand workplace in cultural terms. Queries have been defined based on boolean operators filtering georeferenced interactions[11] located within a circle having a 12 km radius from each city centre and using the following keywords[12]: *work*: a very broad term describing those interactions that don't refer to "leisure" but witness the perception of an effort or duty; *workspace*: specifically a space where a work activity takes place; *workplace*: a *place* – human organization of space – where work activity is conducted; *office*: in reference to both a building and/or a *workplace*; *working*: as *work* but pertaining to the act; *workmeeting:* to show a collective and productive reunion of people in a space which might be formal or occasional. Terms such as *job, position,* or *hiring* have been excluded from the search because generally these terms are posted by recruitment agencies which are not relevant for this research.

4.3. A statistical comparison of spatial patterns and uses

This study aims to compare the point processes for the overall "urban areas" of the three cities: this definition allows for the appreciation of the opposition between "perimeter locations" and "central locations". Instead of considering regional scales – too large for a

[9] The list of NACE codes is provided by EUROSTAT – Statistical classification of economic activities in the European Community (see 'EUROSTAT NACE Codes', n.d.).

[10] This information has been derived and filtered by OS Map Buildings Layer for London and Paris. For Amsterdam more detailed information has been achieved through the Open Geo Data service which includes a detailed GIS survey of building functions.

[11] Georeferenced interactions are about 1% of the overall Twitter stream.

[12] Keywords have been translated into local languages.

Table 1
The spatial statistics' main results qualitatively described. Italic cells underline pattern dissimilarities.

Similarities between the three cities' point patterns

Amsterdam					**Datasets**	
Type of analysis				Selected Twitter interactions	KIBS locations	Office buildings locations
Morphology	Ripley's K-function (conentration vs. dispersion)	**Scale**	Small	Concentrated	Concentrated	*Dispersed*
			Large	Concentrated	Concentrated	Concentrated
	Cluster analysis (monocentric vs. polycentric)		Small	*Polycentric*	Monocentric	Monocentric
			Medium	*Polycentric*	Monocentric	Monocentric
			Large	Monocentric	Monocentric	*Polycentric*
Distance	Mean distances (m) 200 closest points (dataset to dataset)	**Datasets**	Selected Twitter interactions		2104.23	*4241.54*
			KIBS locations	–	–	2599.94
London					**Datasets**	
Type of analysis				Selected Twitter interactions	KIBS Locations	Office buildings locations
Morphology	Ripley's K-function (concentration vs. dispersion)	**Scale**	Small	*Dispersed*	Concentrated	Concentrated
			Large	*Dispersed*	Concentrated	Concentrated
	Cluster analysis (monocentric vs. polycentric)		Small	Monocentric	Monocentric	Monocentric
			Medium	Monocentric	Monocentric	Monocentric
			Large	Monocentric	Monocentric	*Polycentric*
Distance	Mean distances (m) 200 closest points (dataset to dataset)	**Datasets**	Selected Twitter interactions	–	1094.92	3124.49
			KIBS locations	–	–	*8469.59*
Paris					**Datasets**	
Type of analysis				Selected Twitter interactions	KIBS Locations	Office buildings locations
Morphology	Ripley's K-function (concentration vs. dispersion)	**Scale**	Small	*Dispersed*	Concentrated	Concentrated
			Large	*Dispersed*	Concentrated	Concentrated
	Cluster analysis (monocentric vs. polycentric)		Small	Monocentric	Monocentric	*Polycentric*
			Medium	Monocentric	Monocentric	*Polycentric*
			Large	Monocentric	*Polycentric*	Monocentric
Distance	Mean distances (m) 200 closest points (dataset to dataset)	**Datasets**	Selected Twitter interactions	–	783.37	3124.49
			KIBS locations	–	–	*34227.50*

significant evaluation of urban forms – or specific districts – too small for the granularity of the extracted Twitter data – a good definition of "urban areas" was identified respectively as the Amsterdam Urban Region, the London Built Up Area, and the Paris "Petite Couronne" administrative subdivisions.

A multiple distance cluster analysis was conducted to compare to what degree a certain spatial pattern of points behaves differently from the others in its proximity, showing the differences between the agglomerations that are commonly identified by Twitter users as "workplaces" and those identified as office buildings or part of knowledge industries distribution. These differences were measured according to Ripley's K-Function which allows for the computation of the scale of neighbourhood at which a certain set of points becomes clustered or dispersed both for bivariate and univariate analysis. Each cluster was defined on a Euclidean distance radius and classified on the number of points included. The transformation L(d) is defined as:

$$L(d) = \sqrt{\frac{A \sum_{i=1}^{N} \sum_{j=1, j \neq i}^{N} k(i,j)}{\pi N (N-1)}} \quad (1)$$

where A is the total area of the features, N is the number of features, d is the distance, and k(i, j) is the weight, which is 1 (if there is no edge correction) when the distance between i and j is less than or equal to d and 0 when the distance between i and j is greater than d. Here the expected K values have been considered as equal to d. The relative L(d) is then considered as the difference between expected K values and observed ones. L(d) values equal to 0 correspond to a perfectly random distribution, while high L(d) values witness a statistically significant clustering, and negative values indicate a statistically significant dispersion.

Transformation (1) is widely used in spatial statistics and ecology (Levine, 1996; Perry, Miller, & Enright, 2006) and is able to compare bidimensional point processes, intended as a collection of points (*p1, p2, p3 …, pn*) in a region R. Because of its "cumulative nature" (Perry et al., 2006, p. 1) transformation gives very different results to inhomogeneus point patterns. Moreover, when analysing urban patterns, simply opposing "clustered" and "dispersed" points cannot provide insight into the specific type of clustering that is happening at specific distances. In fact, a highly clustered pattern can be both "centralized" and "distributed": a higher quantity of clusters counting a high degree of points would determine a more distributed pattern (polycentric in urban terms) while a small number of high degree clusters indicates a more hierarchical system (monocentric). Therefore, the concept of proximity for a set of points must be combined with their aggregation modularity $Q \in [0,1]$ (see Grindrod & Lee, 2016a,b). If their clustering implies a reciprocal relation based on a Euclidean distance d, it is possible to define a graph $G = (V, E)$ where, for each pair of vertexes $(V1, V2)$ there is an edge E if their Euclidean distance is < d. A modularity close to 1 indicates a clear community structure, while a modularity equal to 0 indicates a complete graph. This analysis defines as communities those point sets that share their reciprocal proximity d, identifying through the method implemented in Wolfram Mathematica

FindGraphCommunities the rank and overall number of each graph subdivision (see Fig. 6). These communities have been classified as clusters with a degree based the number of points included (see Fig. 4).

It is important to underline that every result changes in accordance with point distance values, which measure points' reciprocal proximity. For this reason, it is possible that a certain configuration may give highly distributed clusters for a certain proximity condition but not for others (see Fig. 5).

Moreover, the mean distances between the nearest 200 points has been calculated for each dataset in order to understand the relative spatial proximity of office buildings, knowledge intensive business services, and Twitter interactions (see Table 1).

Another purpose of this analysis is to define and compare user densities for selected Twitter interactions, using this information to identify those buildings, infrastructures, or services that, based on their behavioural settings, are more intensively associated with the collective perception of workplace. Density defined using a Point Kernel Density probability estimation supports the definition of contour lines and areas of density values. For the purpose of this study, a density value of 4 in a range from 1 to 20 has been considered a good measure to compare the three cities.

Thanks to OS Map layers containing building functions and amenities, only those inscribed within the defined density contour were isolated, showing buildings that are more frequently part of the workplace landscape. This information is based only on a footprint's function data, which indicates only a building's most relevant intended uses and doesn't consider diverse uses within the same building. Both knowledge intensive business services and Twitter interactions provide only two-dimensional georeferenced information; therefore, elevation measure couldn't be taken into account. This measure is based on the frequency – and not surface amount – of amenities intersecting the previously defined density area.

5. Findings

What emerges from this empirical comparison, is that there are different patterns in the current demand and supply ratio which are achieved on two levels: spatial organization and use. The cities of London and Paris show similarities, while Amsterdam seems to behave differently. If Amsterdam's offices and knowledge industries are well integrated, they are both far away from workplace culture locations. London and Paris, meanwhile, have a high integration of workplace culture and knowledge intensive business services, while office buildings, even if morphologically similar, are located at significant distances from both (see Table 1). This could indicate that in the three cities office buildings are generally independent from knowledge geographies and workplace perceptions.

Even if this study cannot determine where Twitter interactions happen in terms of architectural space, within all three cities commercial functions such as cafés or shops are a relevant component of the current work practices landscape. Strategically, these spaces might play a key role, one similar to train stations or airports.

5.1. Amsterdam

Amsterdam's morphological structures for a small and medium neighbourhood scale reveal that Twitter interactions are the most polycentric system (see Fig. 5b), while for a 1 km radius office buildings and knowledge geographies become more polycentric (see Fig. 5c). The map also shows a geographical configuration composed of small polycentric places characterized by more intense Twitter activity (see Fig. 1a, b, c) while knowledge intensive business services and offices become distributed for larger areas (see Fig. 5b and c), suggesting that de-localized, large-scale development strategies, which characterized Amsterdam's urban strategies during 1980s–90s, are ill suited for much more concentrated demand (see Fig. 2a). Twitter interactions with high values of proximity are not hierarchical, and the city centre, which hosts the highest number of activities, is set off against other places including Schiphol Airport, Amstel Business Park, and other residential areas (see Fig. 1a).

Amsterdam is the city with the highest mean distances between Twitter interactions and knowledge geographies and between Twitter interactions and office locations (see Table 1). In terms of uses, the analysis shows a strong relevance of commercial buildings, apartments, and hotels (see Fig. 7c). Infrastructures such as train stations also play an important role; in particular, it is interesting to note the intensity of uses at Schiphol Airport, which are almost comparable to those localized in the city centre.

5.2. London

London has the most centralized business service activities and large-scale office building developments of the three cities (see Fig. 1b and c). Compared to Amsterdam and Paris, London has high morphological similarities between clusters of Twitter activities and knowledge geographies (see Fig. 5d, e, f) and small distances between them (see Table 1). In terms of pattern distributions, office buildings are well related with knowledge services (see Fig. 3b).

Small and medium neighbourhood scales clearly align the three points patterns in a highly centralized and hierarchical configuration (see Fig. 5d and e). When considering larger neighbourhood scales, Twitter Interactions and knowledge geographies begin to assume slightly more polycentric localizations (see Fig. 5f). Here it is relevant to observe that office buildings are very centralized in terms of clusters hierarchy (see Fig. 5d, e, f) despite delocalization of some business activities due to development in the Docklands and other areas (see Fig. 1f).

In London, office buildings are similar to workplace perceptions expressed by Twitter data in terms of spatial hierarchy, but in terms of point distributions office buildings and workplace perceptions strongly diverge (see Fig. 2b; Fig. 3b). Moreover, in terms of uses and distances (see Table 1), the map shows a high intensity of Twitter interactions localized in the western part of the city (Soho and Westminister) (see Fig. 1d). In terms of uses, the analysis reveals, as in the case of Amsterdam, a high concentration of retail and commercial buildings (see Fig. 7f). Public buildings including museum and exhibition spaces are also a relevant part of the outlined urban landscape.

5.3. Paris

Office buildings located in Paris maintain a monocentric structure at all scales, while knowledge geographies and Twitter interactions begin to be much more polycentric at the largest scale of 1 km. This monocentric office structure might appear counterintuitive when observing the maps (see Fig. 1i), but it is justified by the large concentration of office buildings in the Défense area. In particular, knowledge geographies at large scales appear as a very clustered distribution (see Fig. 2c), associating the entire western part of the city centre with a high density of points indicating knowledge intensive business services (see also Fig. 1h).

Twitter interactions seem less uniformly distributed than in the other cases and mostly localized in the central core of the city (see Fig. 1g; Fig. 2c; Fig. 3c), where a wide use of retail and civic buildings are also observed (see Fig. 7i). Paris is characterized by a uniform central area represented by the Ile de France, which attracts knowledge industries and is strongly aligned with collective workplace perceptions (see Fig. 1g, h, i). This might suggest an approach that fosters workplace development in small and diffuse locations rather than only a polycentric approach as for La Défense.

6. Conclusions and discussion

Regarding the methodological question addressed by this paper (see

par. 1), this study reveals that spatial media and in particular, Twitter can be tools to integrate knowledge-on-demand configurations within workplace design strategies, interpreting the overall city as a behaviour setting and shifting the design and analytical focus from mere architectures to urban workplaces. In general terms, this study shows that workplace perception, even in a condition of media pervasiveness (see par. 1), is not uniformly dispersed throughout the city: the cultural patterns happen in specific places, which can be more similarly related to knowledge intensive business services locations than office geographies. This make sense especially for European urban conditions, where this study shows that the peripheral relocation of office developments (see par. 1, 4.1.1 and 4.1.3), as has occurred in the cases of Paris and Amsterdam, fails to fit current perceptions of workplace in the city, which are more closely aligned with knowledge services geographies. Investing in the city centre, as in the London case, seems to produce a major integration between spatial proximity factors and "semantic" proximity factors. Investing in city centres in a complex environment such as European cities might raise questions concerning how smart cities can supply current workplace demand: what type of technologies and services, rather than office buildings, will better support the process of work activities densification?

In addition to technological issues, this research contributes to discussions about the future of urban design. This paper further confirms the relevance of commercial amenities, such as food stores and cafés, but it is also relevant that increasing work mobility seems to reveal an intense use of infrastructural buildings, such as train stations and airports, or their close neighbourhoods. This confirms that accessibility and impermanence are factors that can strongly polarize this type of activity. This may lead to further insight into possible future designs of transit hubs that might integrate knowledge intensive business services locations (see par. 5.1). These places, where passengers can spend hours waiting and working, have different conditions than city centres, where social interaction happens more spontaneously; the design of workplaces around or within transit spaces should take account of this different spatiality. Can this impermanence be turned into a resource for urban innovation through urban design solutions?

In conclusion, this paper contributes to the discussion about the future of the European city by reintegrating demand into the traditionally strongly supply-side process of office development. Moreover, this study underlines the importance of workplace design for urban environments and sustainability. As the line between life and work becomes increasingly blurred, and leisure and profession are socially and technologically reconfigured, it is important to move beyond functional definitions of a city's organization that conceive of these activities as separated in time and space, considering digital services as possible resources for urban design solutions within the smart city context.

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